

*TRACE AUTOSHAPING: ACQUISITION,
MAINTENANCE, AND PATH DEPENDENCE AT
LONG TRACE INTERVALS*

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The pigeon's tendency to acquire and maintain signal-directed key pecking under a trace conditioning procedure was parametrically examined. In Experiment 1, the percentage of CS trials with a key peck response was a decreasing function of the trace interval for separate groups of pigeons. The majority of subjects acquired signal-directed key pecking with trace intervals as long as 36 sec. In Experiment 2, differential maintenance of key pecking occurred across trace intervals in a within-subject procedure. Maintenance of key pecking at 36- and 60-sec trace intervals was path dependent in that responding depended on the subject's performance under the preceding trace interval.

Key words: autoshaping, trace conditioning, interstimulus interval, response acquisition, response maintenance, path dependence, key peck, pigeons

Among the procedural variants of the classical conditioning paradigm, Pavlov (1927) described trace conditioning as one in which the aftereffects of a stimulus event (i.e., the stimulus trace) apparently served as an effective stimulus for conditioned responding. Noting the similarity between autoshaping (Brown & Jenkins, 1968) and Pavlovian conditioning, Newlin and LoLordo (1976) explored a variety of classical conditioning procedures within the autoshaping paradigm. In that study, Newlin and LoLordo compared pigeons' autoshaping performance under serial, delay, and trace conditioning procedures. With respect to the trace procedure, these authors reported robust responding to a 4-sec keylight CS that was separated from a food US by a 4-sec trace interval. However, relatively little responding was directed to the CS in a group trained with a 28-sec trace interval.

The pigeon's performance under trace autoshaping procedures is of interest both as it relates to the nature of autoshaped behavior

and as it relates to the pigeon's ability to associate temporally separated events. Newlin and LoLordo (1976) found that key pecking was primarily confined to the CS period during trace procedures, although some "other-directed" pecking often emerged during the trace interval. Given the substantial body of data supporting the stimulus-directed nature of the autoshaped key peck (see Hearst & Jenkins, 1974), we wondered whether stimulus-directed key pecking might not be sensitive to stimulus-reinforcer dependencies across longer trace intervals.

Recent studies of "short-term" memory in the pigeon using matching-to-sample procedures have demonstrated stimulus control on test trials as long as 25 to 60 sec after the sample stimulus (Grant, 1976; Nelson & Wasserman, 1978). Inasmuch as the properties of the stimulus trace that are effective at these extended retention intervals ought to be similar to those necessary to support conditioned responding (Revusky, 1971), these memory studies suggest that the effective interval for trace conditioning in the autoshaping paradigm may extend well beyond the 4-sec value reported by Newlin and LoLordo (1976). However, the retention reported with these relatively long delay intervals has been obtained in conjunction with concurrent training at shorter retention intervals. Pavlov (1927) noted that the temporal interval necessary for the acquisition of conditioned responding may be much briefer than the temporal interval suf-

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ficient to maintain conditioned behavior. Performance at the longer retention intervals in these matching-to-sample studies may, therefore, be more representative of the trace intervals that are effective for the maintenance of conditioned responding than for the acquisition of conditioned responses.

The present studies sought to provide a more detailed assessment of the function relating the stimulus-reinforcer trace interval and the amount of stimulus-directed pecking. In particular, we were interested in whether autoshaped behavior would be acquired and maintained at relatively long trace intervals, and whether training at one trace interval would affect subsequent trace conditioning. Experiment 1 examined autoshaping in pigeons across trace intervals using a between-subjects design. Experiment 2 examined the maintenance of key pecking across trace intervals using a within-subject procedure.

EXPERIMENT 1

Previous studies (Gibbon, Baldock, Locurto, Gold, & Terrace, 1977; Terrace, Gibbon, Farrell, & Baldock, 1975) have shown that lengthening the duration of the intertrial interval relative to the duration of the CS facilitates the acquisition of autoshaped key pecking. Therefore, in order to maximize the opportunity of obtaining conditioned key pecking at longer trace values, we employed relatively long intertrial intervals (160 sec and 480 sec) in the present study. The two intertrial intervals also provided an opportunity to see whether the amount of conditioning obtained at a given trace interval would be determined more by the absolute value of the interval, or by the value of the delay in relation to the total interreinforcer interval. The latter finding would provide support for a correlational model of association (e.g., Gibbon, Berryman, & Thompson, 1974).

Recently, Hinson and Siegel (1980) have shown that inhibitory conditioning may occur to a CS at long trace intervals, suggesting that inhibitory learning may partly determine the interstimulus interval function. Therefore, to ascertain whether inhibitory associations had developed to the CS, the subjects in the present study were transferred to a simple delay conditioning procedure (0-sec trace) following asymptotic performance under the trace pro-

cedure. Responding to the original CS in this condition was then compared with that to a novel CS, presented on alternate trials. Were inhibition to develop to a long-trace CS, then responding to the novel CS should exceed that to the original CS during the transfer phase (Rescorla, 1969).

METHOD

Subjects

Forty experimentally naive feral pigeons were maintained at 80% of their free-feeding weights. All were individually housed in a constantly illuminated colony room with continuous access to water. Subjects were given a daily ration of 2 to 3 g of grit along with supplementary postsession feeding.

Apparatus

Four identical three-key conditioning chambers with aluminum-lined ceilings and walls were used. The interior dimensions of the experimental space were 30 cm by 36 cm wide by 30 cm high. The feeder aperture was 6 cm wide by 5 cm high and was centered on the response panel 10 cm above the wire mesh floor. The three response keys were 1.9 cm in diameter, separated by a distance of 8 cm center to center, and symmetrically located on the response panel 22 cm above the floor. Only the center key was illuminated and used for recording responses in the present study. A minimum force of .03 N through a distance of 2.5 mm was necessary to operate the response key. Stimuli were projected through the transparent Plexiglas surface of the response key from an IEE projector lighted by GE 44 bulbs operated at 5.5 V dc. Houselight for the chamber was provided by a GE 44 bulb at 5.5 V dc, located in an aluminum housing that deflected the light toward the ceiling. The houselight assembly was centered on the response panel 27.5 cm above the floor. During hopper presentations, the aperture was illuminated from within by an ESB 24 bulb operated at 24 V dc. Fresh air and masking noise were provided by a ventilation fan on each chamber. In addition, white noise was continuously present in the room housing the chambers. Scheduling and data recording were managed by a PDP 8/A minicomputer using the SKED software system (Snapper, Stephens, & Lee, 1974).

Procedure

Preliminary training. On the day immediately before the first autoshaping session, each bird was exposed to the experimental chamber and trained to eat readily when the hopper was presented. Adaptation to the hopper was accomplished by placing the pigeon in the chamber with the hopper raised and illuminated. As soon as the bird had eaten for 10 to 12 sec, the hopper was lowered and immediately raised again. This procedure was repeated, with the time between hopper presentations progressively increasing, and the duration of access to food decreasing to 4 sec. After the bird responded readily to a 4-sec hopper presentation, 12 additional food hoppers were presented independently of the subject's behavior on a variable time (VT) 40-sec schedule. In practice, this preliminary procedure resulted in a total of about 20 to 24 hopper presentations to complete hopper training.

Trace conditioning. The conditioned stimulus for each subject was a 12-sec illumination of the center response key with orange light. Each trial consisted of the presentation of the CS, followed by a trace interval (TI) in which stimulus conditions were identical to those present between trials, followed by the US, a 4-sec presentation of the food hopper. The TI was timed from the offset of the keylight to the onset of the food hopper. A variable intertrial interval (ITI) was scheduled between the offset of the food hopper and the onset of the next CS. The houselight was continuously illuminated, except when the food hopper was raised. To accommodate the long ITI values used in the present study, daily sessions were limited to 10 trials. A session was terminated 30 sec following the last hopper presentation each day. Experimental training in this phase lasted for 32 sessions.

The 40 subjects were randomly assigned to 10 groups ($n=4$) resulting from a 2(ITI duration) by 5(TI duration) factorial design. The two mean values used for the ITI were 160 sec and 480 sec. The five values of the TI were 0, 4, 12, 36, and 120 sec. Except for the duration of the trace and intertrial intervals, experimental training was identical for all subjects.

The ITI for each session was scheduled according to a modified sample-without-replacement procedure, so that the first interval of

each session was equal to the mean interval. The nine remaining intervals were randomly assigned so that three were 50% of the mean, three equalled the mean, and three were 150% of the mean ITI. This procedure resulted in daily sessions of a fixed length, and ensured that the variable timing of the ITI did not result in chance differences in the overall rate of reinforcement.

Transfer of training. Following the trace conditioning phase, the subjects in each group were transferred to a 0-sec trace condition (i.e., a simple Pavlovian delayed conditioning procedure) to assess the effects of the trace procedure on subsequent performance. The stimuli in this phase were the original orange keylight and a novel green keylight. The color of the keylight was strictly alternated across trials each day, beginning with the orange keylight. The daily session consisted of 10 trials, 5 with the orange keylight and 5 with the green keylight. All other conditioning parameters were identical to those used in the prior trace procedure. This procedure remained in effect for 16 sessions.

RESULTS

Acquisition

The percentage of CS trials with a key peck is shown in Figure 1 across 4-day blocks for each subject. The left panel shows subjects trained at the 160-sec ITI and the right panel shows subjects trained at the 480-sec ITI. In general, overall responding was an inverse function of the trace interval. Analysis of variance indicated a significant effect of trace interval, $F(4, 30) = 10.43$, $p < .001$, but no significant effect of intertrial interval, $F(1, 30) = .11$, $p > .50$, and a suggestive, but nonsignificant TI by ITI interaction, $F(4, 30) = 1.99$, $p = .12$. The two ITI conditions were, therefore, treated as replications and subsequent comparisons were collapsed across this factor.

The mean percentage of trials with a key peck is shown in Figure 2 for each trace group across the first six sessions. The data for the first session have been further subdivided into two-trial blocks. The initial level of responding for all groups was high, with 14 of the 40 subjects responding to the first CS presentation, and 22 subjects keypecking on at least one of the first two CS presentations. However, despite the high initial tendency to respond to the CS, differential performance began to

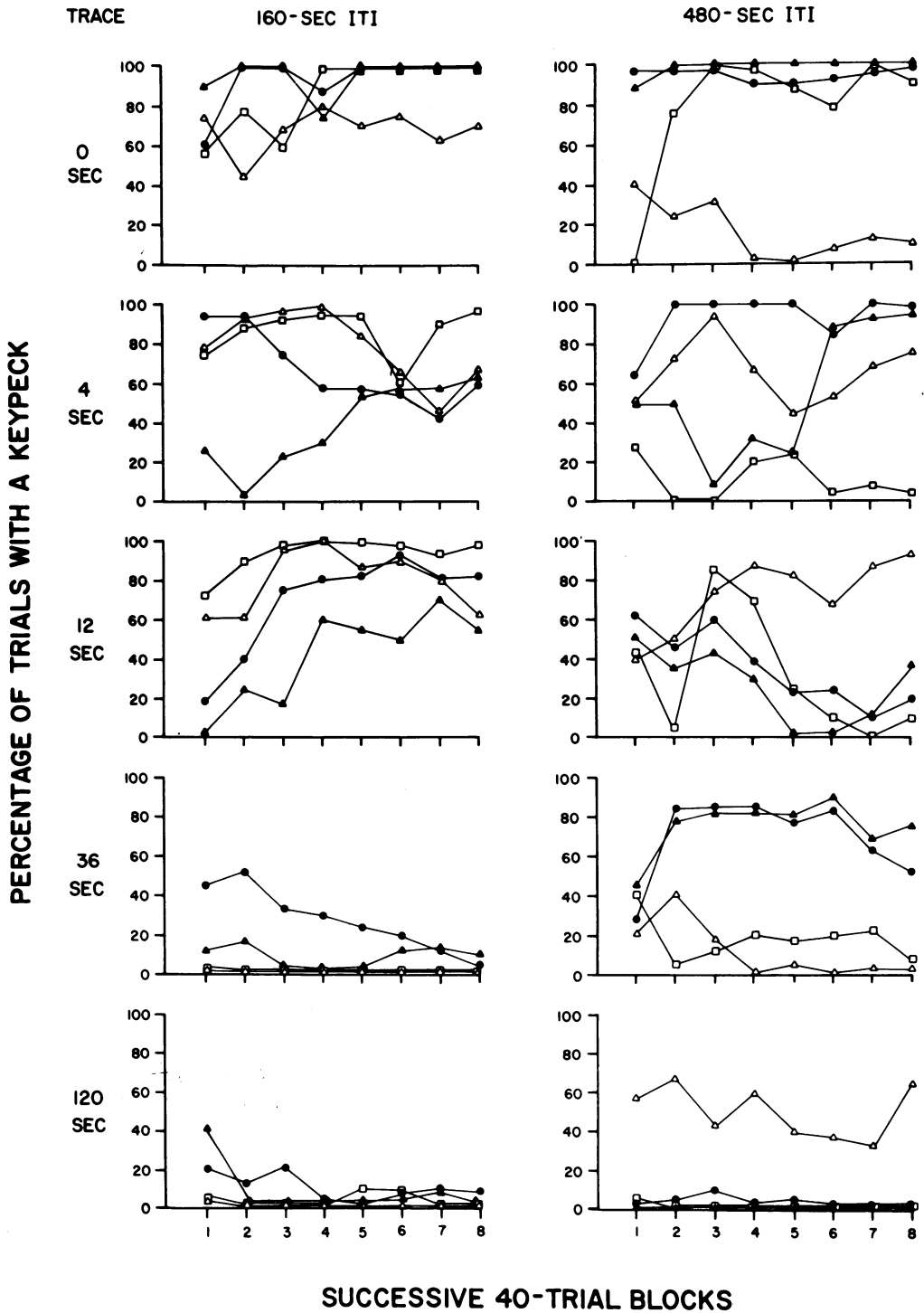


Fig. 1. The percentage of CS trials with a key peck for individual subjects across 4-day (40-trial) blocks in Experiment 1. The left panel shows subjects trained at the 160-sec ITI; the right panel shows subjects trained at the 480-sec ITI. Trace intervals vary from 0 sec (top) to 120 sec (bottom). Symbols for individual subjects correspond to the running position in Table 1 as follows: filled circle, 1; unfilled square, 2; unfilled triangle, 3; filled triangle, 4.

emerge among the groups by the middle of the first session, with the amount of responding to the CS in the three shorter trace groups increasing and responding in the two longer trace groups decreasing.

Figure 3 presents group means for the percentage of CS trials with a key peck and the rate of key pecking during the CS, for the five trace intervals across all 320 trials. Trace intervals are plotted along a logarithmic scale. Both measures decreased monotonically as the trace interval increased. Summary scores for individual subjects, given in Table 1, yielded a significant correlation coefficient, $r(38) = .76$, $p < .001$, indicating that these two measures were not independent. Most subsequent analyses, therefore, emphasize the trials-with-a-key-peck measure.

Table 1 also illustrates that higher rates of key pecking occurred during the CS than during the trace period. Low rates of responding occurred during the ITI and, at shorter traces, rates were generally higher during the TI than during the ITI.

The mean distribution of key pecks within the trial (CS plus TI) is shown across 2-sec bins in Figure 4. These data are based on key pecking across the last 80 trials and are presented for each subject that produced at least 20 responses across these trials. The data for the 120-sec trace group were deleted since only one subject maintained substantial key pecking at this interval. The data in each 2-sec bin are plotted as a ratio of the individual subject's mean key pecking rate during the CS. Thus, a ratio above unity indicates that a response rate above the subject's mean rate occurred during that time bin, whereas a ratio below unity indicates a lower-than-mean response rate in that 2-sec bin. Response rate during the trace interval is also plotted relative to the mean CS key-pecking rate to facilitate comparisons between CS- and trace-interval key pecking patterns. The distribution of key pecking was similar for subjects in each trace group, with the highest proportion of key pecks occurring in the first 4 sec of the 12-sec CS. With few exceptions, the response

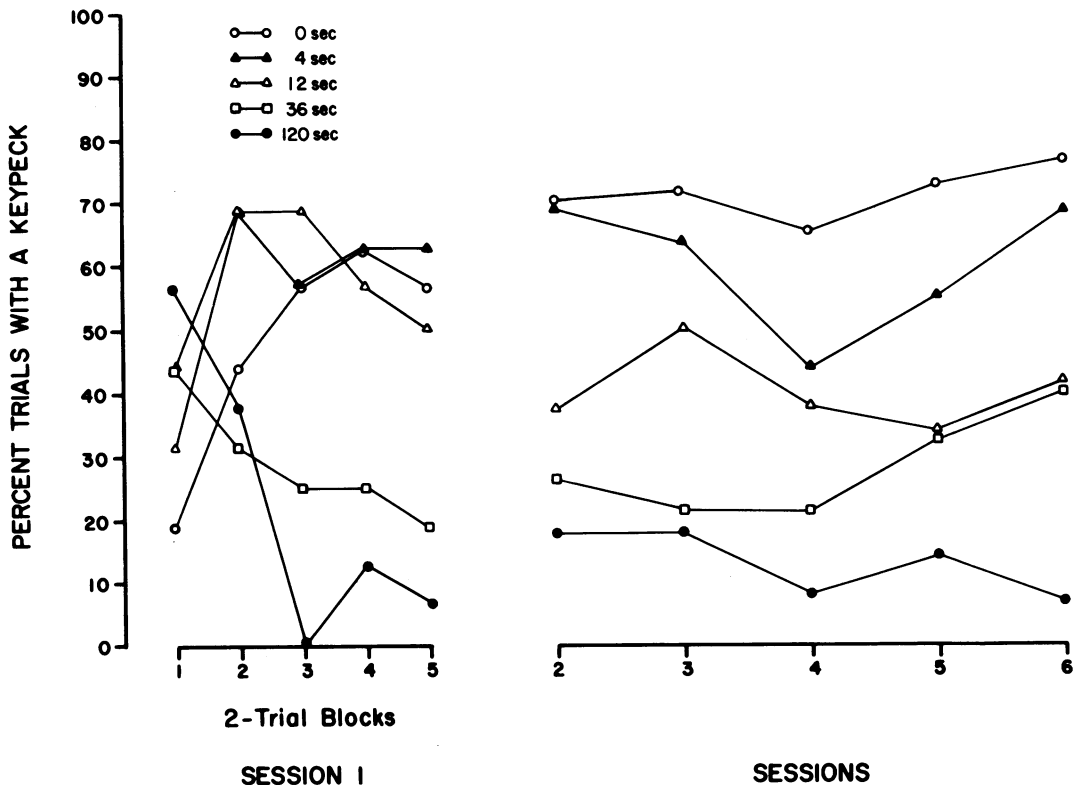


Fig. 2. The mean percentage of CS trials with a key peck for each group ($n = 8$) trained at the 0-sec, 4-sec, 12-sec, 36-sec, and 120-sec trace intervals in Experiment 1. Data are presented across the first six sessions, with the first session further subdivided into 2-trial blocks.

Table 1

Summary measures for each subject in Experiment 1. Data are means based on performance across all 320 trials. Standard errors for the group means are given in parentheses.

| Inter-trial interval | Running position* | Trace Intervals | | | | | Inter-trial interval | Running position* | Trace Intervals | | | | |
|--|-------------------|-----------------|-------|--------|--------|---------|---|-------------------|-----------------|--------|--------|--------|---------|
| | | 0 sec | 4 sec | 12 sec | 36 sec | 120 sec | | | 0 sec | 4 sec | 12 sec | 36 sec | 120 sec |
| Percentage of CS Trials with a Peck | | | | | | | 2 | 34.08 | 2.88 | 6.06 | 1.50 | 0.17 | |
| 160 | 1 | 92.81 | 67.25 | 68.75 | 27.81 | 9.38 | 3 | 1.64 | 5.99 | 14.63 | 1.49 | 13.05 | |
| | 2 | 86.88 | 86.56 | 93.50 | 0.31 | 3.13 | 4 | 87.28 | 10.31 | 3.58 | 14.25 | 0.00 | |
| | 3 | 70.00 | 79.06 | 79.06 | 0.31 | 0.31 | Mean | 38.99 | 21.69 | 13.34 | 5.92 | 2.20 | |
| | 4 | 95.31 | 39.13 | 41.88 | 8.44 | 7.19 | S.E. | (10.20) | (10.17) | (4.11) | (3.08) | (1.58) | |
| | Mean | 78.87 | 62.24 | 56.03 | 26.33 | 9.22 | Mean Responses per Minute During Trace Intervals | | | | | | |
| 480 | 1 | 94.69 | 93.44 | 35.31 | 69.69 | 2.81 | 160 | 1 | — | 20.77 | 0.35 | 0.07 | 0.03 |
| | 2 | 78.44 | 11.25 | 30.63 | 18.13 | 0.63 | 2 | — | 4.22 | 56.61 | 0.01 | 0.00 | |
| | 3 | 14.38 | 65.63 | 72.88 | 10.94 | 50.31 | 3 | — | 10.50 | 0.25 | 0.00 | 0.00 | |
| | 4 | 98.44 | 55.63 | 26.25 | 75.00 | 0.00 | 4 | — | 0.28 | 0.38 | 0.12 | 0.04 | |
| | Mean | 78.87 | 62.24 | 56.03 | 26.33 | 9.22 | 480 | 1 | — | 23.30 | 0.03 | 0.20 | 0.00 |
| Percentage of Trace Intervals with a Peck | | | | | | | 2 | — | 0.33 | 0.14 | 0.09 | 0.00 | |
| 160 | 1 | — | 52.81 | 3.13 | 2.81 | 3.44 | 3 | — | 0.42 | 0.22 | 0.49 | 0.37 | |
| | 2 | — | 11.88 | 72.50 | 0.31 | 0.63 | 4 | — | 2.67 | 5.91 | 0.39 | 0.00 | |
| | 3 | — | 32.88 | 4.38 | 0.00 | 0.00 | Mean | 7.81 | 7.99 | 0.17 | 0.06 | | |
| | 4 | — | 1.56 | 3.13 | 3.75 | 3.75 | S.E. | (3.33) | (6.98) | (0.06) | (0.05) | | |
| | Mean | — | 24.97 | 16.25 | 5.12 | 4.57 | Mean Responses per Minute During Intertrial Intervals | | | | | | |
| 480 | 1 | — | 83.13 | 0.63 | 7.19 | 0.00 | 160 | 1 | 0.65 | 1.45 | 0.12 | 0.02 | 0.06 |
| | 2 | — | 1.56 | 1.88 | 2.50 | 0.31 | 2 | 0.15 | 0.68 | 1.44 | 0.05 | 0.01 | |
| | 3 | — | 2.19 | 2.50 | 14.69 | 28.44 | 3 | 0.03 | 1.34 | 0.00 | 0.00 | 0.00 | |
| | 4 | — | 13.75 | 41.88 | 9.69 | 0.00 | 4 | 0.47 | 0.34 | 0.09 | 0.02 | 0.05 | |
| | Mean | — | 24.97 | 16.25 | 5.12 | 4.57 | 480 | 1 | 0.02 | 1.34 | 0.00 | 0.59 | 0.00 |
| Mean Responses per Minute During CS Trials | | | | | | | 2 | 0.17 | 0.25 | 0.10 | 0.44 | 0.00 | |
| 160 | 1 | 39.67 | 10.87 | 13.08 | 3.60 | 1.98 | 3 | 0.10 | 0.13 | 0.11 | 0.25 | 0.27 | |
| | 2 | 66.49 | 29.58 | 38.60 | 0.02 | 0.36 | 4 | 0.23 | 0.13 | 1.13 | 0.56 | 0.00 | |
| | 3 | 7.52 | 20.08 | 19.28 | 0.05 | 0.02 | Mean | 0.23 | 0.71 | 0.37 | 0.24 | 0.05 | |
| | 4 | 50.25 | 4.38 | 7.64 | 2.22 | 1.86 | S.E. | (0.08) | (0.21) | (0.20) | (0.09) | (0.03) | |
| | Mean | 24.97 | 89.40 | 3.85 | 24.22 | 0.16 | | | | | | | |
| 480 | 1 | 24.97 | 89.40 | 3.85 | 24.22 | 0.16 | 160 | 1 | 0.65 | 1.45 | 0.12 | 0.02 | 0.06 |
| | 2 | 66.49 | 29.58 | 38.60 | 0.02 | 0.36 | 2 | 0.15 | 0.68 | 1.44 | 0.05 | 0.01 | |
| | 3 | 7.52 | 20.08 | 19.28 | 0.05 | 0.02 | 3 | 0.03 | 1.34 | 0.00 | 0.00 | 0.00 | |
| | 4 | 50.25 | 4.38 | 7.64 | 2.22 | 1.86 | 4 | 0.47 | 0.34 | 0.09 | 0.02 | 0.05 | |
| | Mean | 24.97 | 89.40 | 3.85 | 24.22 | 0.16 | 480 | 1 | 0.02 | 1.34 | 0.00 | 0.59 | 0.00 |
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| | 4 | 50.25 | 4.38 | 7.64 | 2.22 | 1.86 | S.E. | (0.08) | (0.21) | (0.20) | (0.09) | (0.03) | |
| | Mean | 24.97 | 89.40 | 3.85 | 24.22 | 0.16 | | | | | | | |
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| | 3 | 7.52 | 20.08 | 19.28 | 0.05 | 0.02 | 3 | 0.03 | 1.34 | 0.00 | 0.00 | 0.00 | |
| | 4 | 50.25 | 4.38 | 7.64 | 2.22 | 1.86 | 4 | 0.47 | 0.34 | 0.09 | 0.02 | 0.05 | |
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| | 3 | 7.52 | 20.08 | 19.28 | 0.05 | 0.02 | Mean | 0.23 | 0.71 | 0.37 | 0.24 | 0.05 | |
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| | 3 | 7.52 | 20.08 | 19.28 | 0.05 | 0.02 | 3 | 0.03 | 1.34 | 0.00 | 0.00 | 0.00 | |
| | 4 | 50.25 | 4.38 | 7.64 | 2.22 | 1.86 | 4 | 0.47 | 0.34 | 0.09 | 0.02 | 0.05 | |
| | Mean | 24.97 | 89.40 | 3.85 | 24.22 | 0.16 | 480 | 1 | 0.02 | 1.34 | 0.00 | 0.59 | 0.00 |
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| 480 | 1 | 24.97 | 89.40 | 3.85 | 24.22 | 0.16 | 160 | 1 | 0.65 | 1.45 | 0.12 | 0.02 | 0.06 |
| | 2 | 66.49 | 29.58 | 38.60 | 0.02 | 0.36 | 2 | 0.15 | 0.68 | 1.44 | 0.05 | 0.01 | |
| | 3 | 7.52 | 20.08 | 19.28 | 0.05 | 0.02 | 3 | 0.03 | 1.34 | 0.00 | 0.00 | 0.00 | |
| | 4 | 50.25 | 4.38 | 7.64 | 2.22 | 1.86 | 4 | 0.47 | 0.34 | 0.09 | 0.02 | 0.05 | |
| | Mean | 24.97 | 89.40 | 3.85 | 24.22 | 0.16 | 480 | 1 | 0.02 | 1.34 | 0.00 | 0.59 | 0.00 |
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| | 2 | 66.49 | 29.58 | 38.60 | 0.02 | 0.36 | 4 | 0.23 | 0.13 | 1.13 | 0.56 | 0.00 | |
| | 3 | 7.52 | 20.08 | 19.28 | 0.05 | 0.02 | Mean | 0.23 | 0.71 | 0.37 | 0.24 | 0.05 | |
| | 4 | 50.25 | 4.38 | 7.64 | 2.22 | 1.86 | S.E. | (0.08) | (0.21) | (0.20) | (0.09) | (0.03) | |
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| | 2 | 66.49 | 29.58 | 38.60 | 0.02 | 0.36 | 2 | 0.15 | 0.68 | 1.44 | 0.05 | 0.01 | |
| | 3 | 7.52 | 20.08 | 19.28 | 0.05 | 0.02 | 3 | 0.03 | 1.34 | 0.00 | 0.00 | 0.00 | |
| | 4 | 50.25 | 4.38 | 7.64 | 2.22 | 1.86 | 4 | 0.47 | 0.34 | 0.09 | 0.02 | 0.05 | |
| | Mean | 24.97 | 89.40 | 3.85 | 24.22 | 0.16 | 480 | 1 | 0.02 | 1.34 | 0.00 | 0.59 | 0.00 |
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| | 2 | 66.49 | 29.58 | 38.60 | 0.02 | 0.36 | 4 | 0.23 | 0.13 | 1.13 | 0.56 | 0.00 | |
| | 3 | 7.52 | 20.08 | 19.28 | 0.05 | 0.02 | Mean | 0.23 | 0.71 | 0.37 | 0.24 | 0.05 | |
| | 4 | 50.25 | 4.38 | 7.64 | 2.22 | 1.86 | S.E. | (0.08) | (0.21) | (0.20) | (0.09) | (0.03) | |
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| | 3 | 7.52 | 20.08 | 19.28 | 0.05 | 0.02 | 3 | 0.03 | 1.34 | 0.00 | 0.00 | 0.00 | |
| | 4 | 50.25 | 4.38 | 7.64 | 2.22 | 1.86 | 4 | 0.47 | 0.34 | 0.09 | 0.02 | 0.05 | |
| | Mean | 24.97 | 89.40 | 3.85 | 24.22 | 0.16 | 480 | 1 | 0.02 | 1.34 | 0.00 | 0.59 | 0.00 |
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| | 2 | 66.49 | 29.58 | 38.60 | 0.02 | 0.36 | 4 | 0.23 | 0.13 | 1.13 | 0.56 | 0.00 | |
| | 3 | 7.52 | 20.08 | 19.28 | 0.05 | 0.02 | Mean | 0.23 | 0.71 | 0.37 | 0.24 | 0.05 | |
| | 4 | 50.25 | 4.38 | 7.64 | 2.22 | 1.86 | S.E. | (0.08) | (0.21) | (0.20) | (0.09) | (0.03) | |
| | Mean | 24.97 | 89.40 | 3.85 | 24.22 | 0.16 | | | | | | | |
| 480 | 1 | 24.97 | 89.40 | 3.85 | 24.22 | 0.16 | 160 | 1 | 0.65 | 1.45 | 0.12 | 0.02 | 0.06 |
| | 2 | 66.49 | 29.58 | 38.60 | 0.02 | 0.36 | 2 | 0.15 | 0.68 | 1.44 | 0.05 | 0.01 | |
| | 3 | 7.52 | 20.08 | 19.28 | 0.05 | 0.02 | 3 | 0.03 | 1.34 | 0.00 | 0.00 | 0.00 | |
| | 4 | 50.25 | 4.38 | 7.64 | 2.22 | 1.86 | 4 | 0.47 | 0.34 | 0.09 | 0.02 | 0.05 | |
| | Mean | 24.97 | 89.40 | 3.85 | 24.22 | 0.16 | 480 | 1 | 0.02 | 1.34 | 0.00 | 0.59 | 0.00 |
| Mean Responses per Minute During CS Trials | | | | | | | 2 | 0.17 | 0.25 | 0.10 | 0.44 | 0.00 | |
| 160 | 1 | 39.67 | 10.87 | 13.08 | 3.60 | 1.98 | 3 | 0.10 | 0.13 | 0.11 | 0.25 | 0.27 | |
| | 2 | 66.49 | 29.58 | 38.60 | 0.02 | 0.36 | 4 | 0.23 | 0.13 | 1.13 | 0.56 | 0.00 | |
| | 3 | 7.52 | 20.08 | 19.28 | 0.05 | 0.02 | Mean | 0.23 | 0.71 | 0.37 | 0.24 | 0.05 | |
| | 4 | 50.25 | 4.38 | 7.64 | 2.22 | 1.86 | S.E. | (0.08) | (0.21) | (0.20) | (0.09) | (0.03) | |
| | Mean | 24.97 | 89.40 | 3.85 | 24.22 | 0.16 | | | | | | | |
| 480 | 1 | 24.97 | 89.40 | 3.85 | 24.22 | 0.16 | 160 | 1 | 0.65 | 1.45 | 0.12 | 0.02 | 0.06 |
| | 2 | 66.49 | 29.58 | 38.60 | 0.02 | 0.36 | 2 | 0.15 | 0.68 | 1.44 | 0.05 | 0.01 | |
| | 3 | 7.52 | 20.08 | 19.28 | 0.05 | 0.02 | 3 | 0.03 | 1.34 | 0.00 | 0.00 | 0.00 | |
| | 4 | 50.25 | 4.38 | 7.64 | 2.22 | 1.86 | 4 | 0.47 | 0.34 | 0.09 | 0.02 | 0.05 | |
| | Mean | 24.97 | 89.40 | 3.85 | 24.22 | 0.16 | 480 | 1 | 0.02 | 1.34 | 0.00 | 0.59 | 0.00 |
| Mean Responses per Minute During CS Trials | | | | | | | 2 | 0.17 | 0.25 | 0.10 | 0.44 | 0.00 | |
| 160 | 1 | 39.67 | 10.87 | 13.08 | 3.60 | 1.98 | 3 | 0.10 | 0.13 | 0.11 | 0.25 | 0.27 | |
| | 2 | 66.49 | 29.58 | 38.60 | 0.02 | 0.36 | 4 | 0.23 | 0.13 | 1.13 | 0.56 | 0.00 | |
| | 3 | 7.52 | 20.08 | 19.28 | 0.05 | 0.02 | Mean | 0.23 | 0.71 | 0.37 | 0.24 | 0.05 | |
| | 4 | 50.25 | 4.38 | 7.64 | 2.22 | 1.86 | S.E. | (0.08) | (0.21) | (0.20) | (0.09) | (0.03) | |
| | Mean | 24.97 | 89.40 | 3.85 | 24.22 | 0.16 | | | | | | | |
| 480 | 1 | 24.97 | 89.40 | 3.85 | 24.22 | 0.16 | 160 | 1 | 0.65 | 1.45 | 0.12 | 0.02 | 0.06 |
| | 2 | 66.49 | 29.58 | 38.60 | 0.02 | 0.36 | 2 | 0.15 | 0. | | | | |

Table 2

Percentage of trials with a response for the original and novel stimulus. Data are based on the first 4 days of the transfer test in Experiment 1.

| Inter-trial interval | Running position* | Trace Intervals | | | | | Inter-trial interval | Running position* | Trace Intervals | | | | |
|----------------------|-------------------|-----------------|-------|--------|--------|---------|----------------------|-------------------|-----------------|-------|--------|--------|---------|
| | | 0 sec | 4 sec | 12 sec | 36 sec | 120 sec | | | 0 sec | 4 sec | 12 sec | 36 sec | 120 sec |
| Original Stimulus | | | | | | | Novel Stimulus | | | | | | |
| 160 | 1 | 100 | 70 | 70 | 70 | 5 | 160 | 1 | 95 | 70 | 75 | 65 | 15 |
| | 2 | 100 | 95 | 85 | 45 | 5 | | 2 | 100 | 90 | 95 | 55 | 40 |
| | 3 | 55 | 55 | 80 | 55 | 5 | | 3 | 40 | 10 | 75 | 60 | 10 |
| | 4 | 100 | 50 | 90 | 85 | 0 | | 4 | 100 | 45 | 85 | 85 | 5 |
| 480 | 1 | 90 | 100 | 10 | 75 | 0 | 480 | 1 | 85 | 90 | 30 | 65 | 0 |
| | 2 | 75 | 25 | 25 | 25 | 55 | | 2 | 60 | 80 | 30 | 35 | 85 |
| | 3 | 0 | 55 | 55 | 5 | 60 | | 3 | 15 | 55 | 25 | 35 | 100 |
| | 4 | 95 | 80 | 0 | 70 | 50 | | 4 | 85 | 70 | 10 | 70 | 45 |
| | Mean | 77 | 66 | 52 | 54 | 23 | | Mean | 73 | 64 | 53 | 59 | 35 |
| | S.E. | (13) | (9) | (13) | (10) | (10) | | S.E. | (12) | (10) | (12) | (6) | (13) |

*Note: Each data entry within a measurement condition represents a single subject's data. Data entries from the same subject are listed in the corresponding running position across conditions.

block, then 100% of the subjects trained at the 0-, 4-, and 12-sec trace intervals, 62% of the subjects trained at the 36-sec interval, and 25% of the subjects trained at the 120-sec trace interval acquired autoshaped key pecking.

These values extend well beyond the 4-sec duration previously shown to be effective in the acquisition of autoshaped key pecking (Newlin & LoLordo, 1976). Most of the subjects that did maintain key pecking to the CS

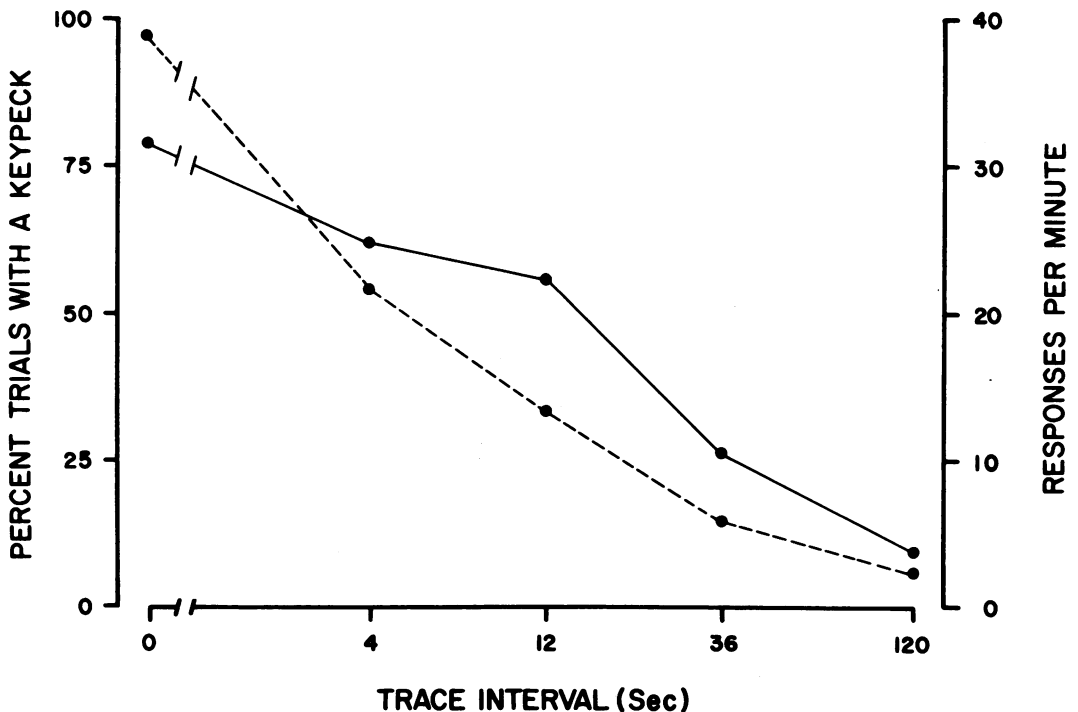


Fig. 3. The mean overall percentage of CS trials with a key peck (solid line, left vertical axis) and the mean overall rate of key pecking during the CS (dashed line, right vertical axis) for each group of subjects ($n = 8$) as a function of the trace interval used in training in Experiment 1. Note, trace intervals are presented on a logarithmic scale.

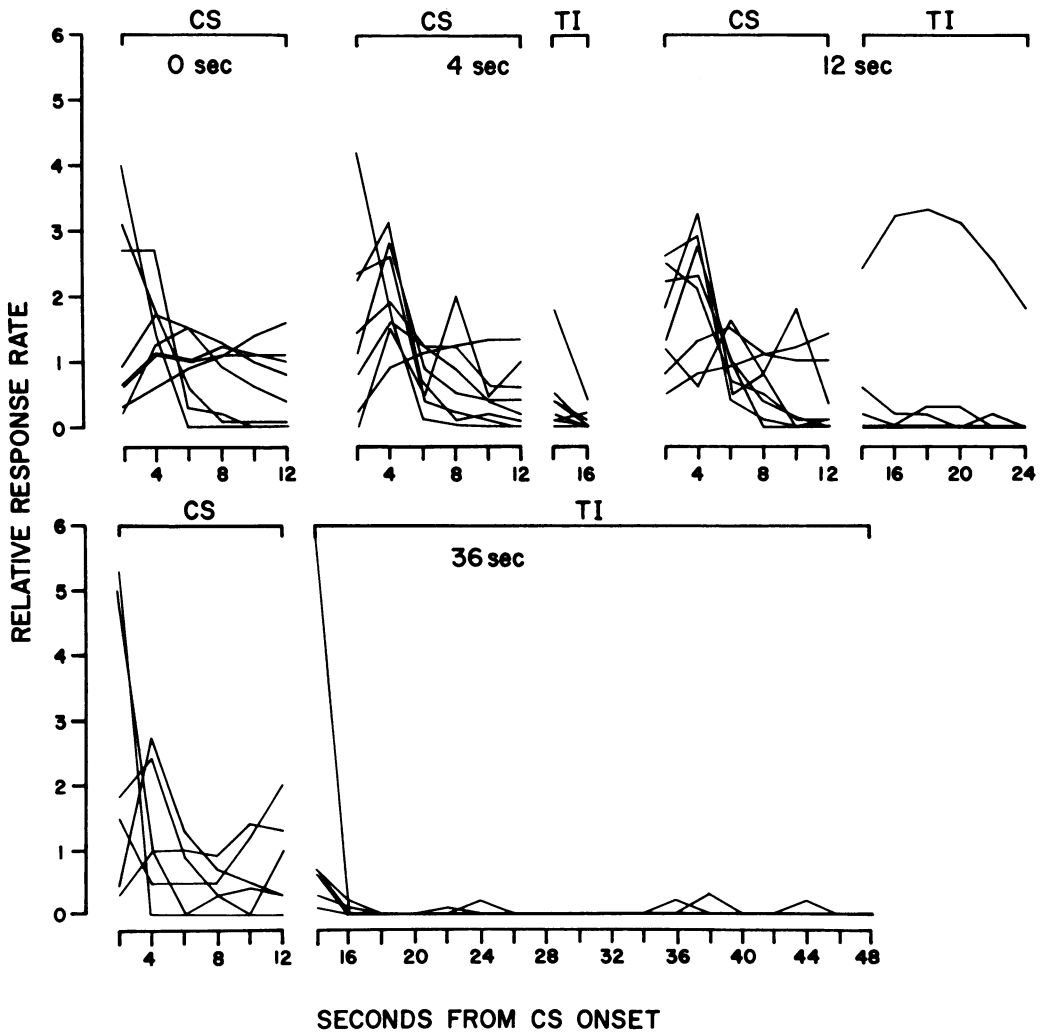


Fig. 4. The relative rate of key pecking during the trial (CS plus TI) across successive 2-sec time periods in Experiment 1. Data are based on performance maintained during the last 80 trials for subjects in the 0-sec, 4-sec, 12-sec, and 36-sec trace groups. Response rates in each 2-sec period are plotted relative to the individual subject's mean response rate during the CS. See text for additional details.

at the longer trace intervals were trained at the 480-sec ITI. Although these data provide suggestive evidence to support a correlational model of association (Gibbon *et al.*, 1974), statistical analysis was only marginally significant.

The transfer of training procedure did not yield strong support for inhibitory conditioning to the CS at longer trace intervals. However, the transfer procedure produced rapid and abrupt changes in performance. Relative to the novel CS, the amount of key pecking directed to the original keylight was in the direction that would be expected if longer trace values retarded key pecking to the origi-

nal stimulus. As seen in Table 2, the number of subjects that responded more to the original CS than to the novel CS was inversely related to the trace interval. The absence of a statistically significant interaction, therefore, may have resulted from insensitivity of the present design to the rapid changes in performance obtained.

The number of subjects (14 of 40) responding to the keylight on the first autoshaping trial was higher than we had anticipated, but not unprecedented in the autoshaping literature. Several authors (e.g., Downing & Neuringer, 1976; Steinhauer, Davol, & Lee, 1976) have reported high initial response levels in

the autoshaping paradigm, possibly produced by generalized magazine responding. In addition, the present design used relatively long ITI periods, a factor known to reduce the number of trials necessary to establish key pecking (Gibbon, et al., 1977; Terrace et al., 1975), presumably through associative mechanisms. Whatever the source of the initial tendency to key peck, it is clear that the subsequent level of responding to the CS was markedly influenced by the trace interval.

Our results are consistent with Newlin and LoLordo's (1976) observation that more key pecking occurred during the CS than during the trace interval. Although the absolute rate of responding during a trial declined as a function of the trace interval (Wasserman, 1973), the relative distribution of key pecking across time during the CS and the trace interval was highly similar across groups. For many subjects, key pecking at the start of the trace interval may have resulted from carryover CS-directed pecks occurring at the end of the CS

period. For several other subjects, however, the distribution of key pecking appeared to punctuate the stimulus changes on the response key, with relatively active periods of key pecking both during the first few seconds following CS onset and during the first few seconds following CS offset. Few subjects key pecked during the later portion of the trace interval.

EXPERIMENT 2

Experiment 1 demonstrated that pigeons do acquire key pecking to a keylight CS at extended trace intervals. The present study sought to examine the maintenance of key pecking under various traces using a within-subject design. The within-subject procedure also provided an opportunity to examine the effects of training at one trace interval on performance at a subsequent trace interval. For this purpose, subjects were exposed to selected trace intervals after training at both longer and shorter traces.

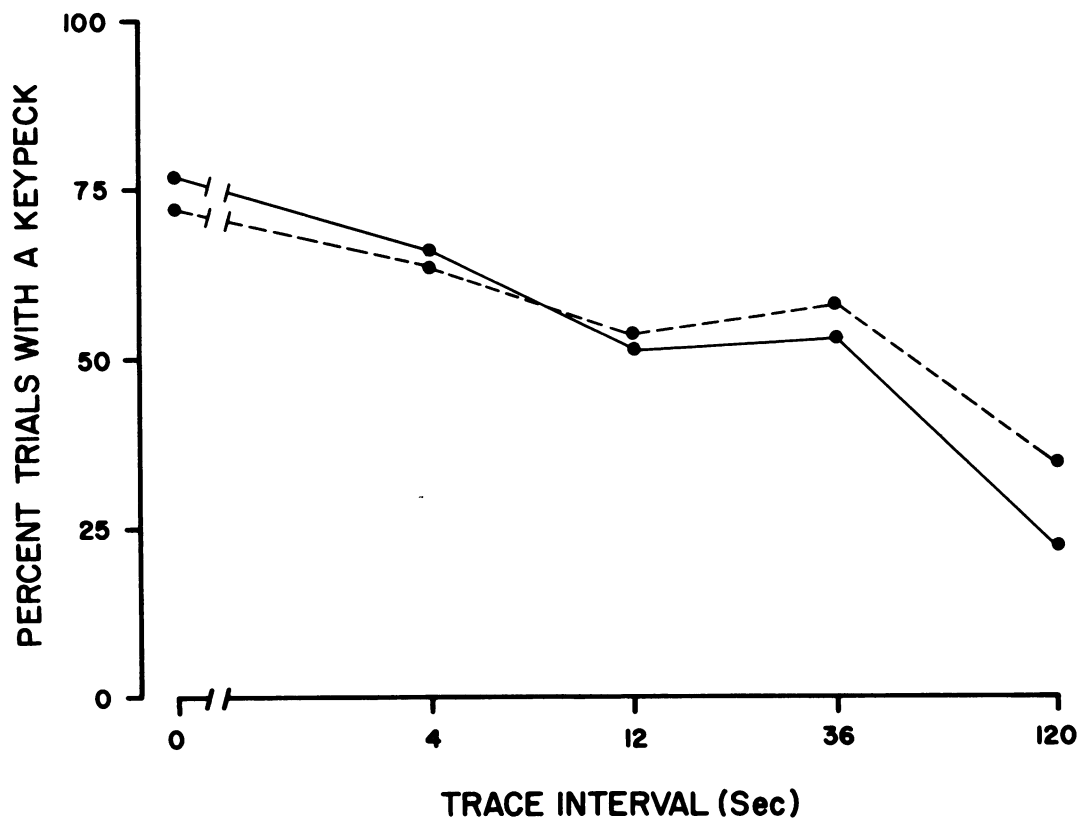


Fig. 5. The mean percentage of CS trials with a key peck to the original keylight (solid line) and the novel keylight (dashed line) during the first 40 trials of the transfer phase in Experiment 1. Data are plotted for each group ($n=8$) as a function of the trace interval used in training. Note, trace intervals are presented on a logarithmic scale.

Table 3

The percentage of trials with a key peck and key pecking response rates during the keylight (CS) and Trace Interval (TI) periods from the last 4 days of each phase in Experiment 2. Standard errors for the group means are shown in parentheses.

| Phase | Trace inter- val (sec) | Days run | Sub- ject | % Trials with key peck | | Responses per minute | | Phase | Trace inter- val (sec) | Days run | Sub- ject | % Trials with key peck | | Responses per minute | |
|-------|---------------------------------|-------------|--------------|---------------------------|--------|-------------------------|-------|-------|---------------------------------|-------------|--------------|---------------------------|-------|-------------------------|-------|
| | | | | CS | TI | CS | TI | | | | | CS | TI | CS | TI |
| 1 | 12 | 12 | 1 | 90.0 | 12.5 | 17.9 | 1.1 | 7 | 12 | 12 | 1 | 12.5 | 2.5 | 1.8 | 0.1 |
| | | | 2 | 72.5 | 100.0 | 6.8 | 9.4 | | | | 2 | 42.5 | 0.0 | 3.5 | 0.0 |
| | | | 3 | 95.0 | 2.5 | 13.6 | 0.1 | | | | 3 | 67.5 | 2.5 | 12.4 | 0.1 |
| | | | 4 | 90.0 | 5.0 | 32.9 | 0.4 | | | | 4 | 50.0 | 0.0 | 7.1 | 0.0 |
| | | | Mean | 86.9 | 30.0 | 17.8 | 2.8 | | | | Mean | 43.1 | 1.3 | 6.2 | 0.1 |
| | | | S.E. | (4.9) | (23.4) | (5.5) | (2.2) | | | | S.E. | (11.5) | (0.7) | (2.3) | (0.0) |
| 2 | 36 | 12 | 1 | 45.0 | 30.0 | 12.5 | 5.3 | 8 | 36 | 24 | 1 | 17.5 | 0.0 | 1.9 | 0.0 |
| | | | 2 | 95.0 | 40.0 | 16.0 | 2.9 | | | | 2 | 45.0 | 5.0 | 3.8 | 0.3 |
| | | | 3 | 50.0 | 7.5 | 11.1 | 1.1 | | | | 3 | 52.5 | 5.0 | 11.8 | 0.9 |
| | | | 4 | 42.5 | 12.5 | 8.5 | 0.6 | | | | 4 | 42.5 | 0.0 | 7.6 | 0.0 |
| | | | Mean | 58.1 | 22.5 | 12.0 | 2.5 | | | | Mean | 39.4 | 2.5 | 6.3 | 0.3 |
| | | | S.E. | (12.4) | (7.6) | (1.6) | (1.1) | | | | S.E. | (7.6) | (1.4) | (2.2) | (0.2) |
| 3 | 60 | 12 | 1 | 42.5 | 10.0 | 8.6 | 0.9 | 9 | 120 | 28 | 1 | 15.0 | 10.0 | 1.6 | 0.5 |
| | | | 2 | 70.0 | 12.5 | 7.9 | 0.6 | | | | 2 | 22.5 | 0.0 | 3.0 | 0.0 |
| | | | 3 | 35.0 | 12.5 | 8.1 | 2.0 | | | | 3 | 30.0 | 7.5 | 15.8 | 0.8 |
| | | | 4 | 55.0 | 32.5 | 30.3 | 1.6 | | | | 4 | 5.0 | 2.5 | 1.1 | 0.1 |
| | | | Mean | 50.6 | 16.9 | 13.7 | 1.3 | | | | Mean | 18.1 | 5.0 | 5.4 | 0.4 |
| | | | S.E. | (7.7) | (5.2) | (5.5) | (0.3) | | | | S.E. | (5.3) | (2.3) | (3.5) | (0.2) |
| 4 | 120 | 12 | 1 | 17.5 | 2.5 | 2.4 | 0.1 | 10 | 36 | 24 | 1 | 5.0 | 0.0 | 0.3 | 0.0 |
| | | | 2 | 47.5 | 30.0 | 7.1 | 1.8 | | | | 2 | 15.0 | 2.5 | 2.1 | 0.1 |
| | | | 3 | 27.5 | 2.5 | 6.8 | 0.1 | | | | 3 | 12.5 | 5.0 | 3.1 | 0.8 |
| | | | 4 | 25.0 | 10.0 | 15.5 | 0.5 | | | | 4 | 2.5 | 0.0 | 0.1 | 0.0 |
| | | | Mean | 29.4 | 11.3 | 8.0 | 0.6 | | | | Mean | 8.8 | 1.9 | 1.4 | 0.2 |
| | | | S.E. | (6.4) | (6.5) | (2.7) | (0.4) | | | | S.E. | (3.0) | (1.2) | (0.7) | (0.2) |
| 5 | 60 | 12 | 1 | 7.5 | 5.0 | 2.6 | 0.3 | 11 | 12 | 24 | 1 | 22.5 | 0.0 | 2.6 | 0.0 |
| | | | 2 | 37.5 | 15.0 | 6.5 | 1.1 | | | | 2 | 40.0 | 22.5 | 7.5 | 1.4 |
| | | | 3 | 12.5 | 5.0 | 3.6 | 1.1 | | | | 3 | 67.5 | 0.0 | 20.8 | 0.0 |
| | | | 4 | 15.0 | 7.5 | 11.1 | 0.4 | | | | 4 | 67.5 | 2.5 | 26.5 | 1.8 |
| | | | Mean | 18.1 | 8.1 | 6.0 | 0.7 | | | | Mean | 49.4 | 6.3 | 14.4 | 0.8 |
| | | | S.E. | (6.6) | (2.4) | (1.9) | (0.2) | | | | S.E. | (11.1) | (5.4) | (5.6) | (0.5) |
| 6 | 36 | 12 | 1 | 0.0 | 0.0 | 0.0 | 0.0 | 12 | 60 | 36* | 1 | 10.0 | 2.5 | 1.0 | 0.1 |
| | | | 2 | 25.0 | 2.5 | 2.4 | 0.1 | | | | 2 | 20.0 | 25.0 | 4.3 | 1.3 |
| | | | 3 | 30.0 | 7.5 | 11.8 | 0.4 | | | | 3 | 50.0 | 2.5 | 10.3 | 0.3 |
| | | | 4 | 25.0 | 5.0 | 7.4 | 0.3 | | | | 4 | 57.5 | 10.0 | 15.9 | 0.5 |
| | | | Mean | 20.0 | 3.8 | 5.4 | 0.2 | | | | Mean | 34.4 | 10.0 | 7.9 | 0.6 |
| | | | S.E. | (6.8) | (1.6) | (2.6) | (0.1) | | | | S.E. | (11.5) | (5.3) | (3.3) | (0.3) |

*Note: Data reported for subject 2 in this condition are based on performance during the last 4 of 24 days.

METHOD

Subjects

The four pigeons trained under the 12-sec trace, 160-sec ITI condition in Experiment 1 served. They were maintained in their home cages at 80% of their ad lib weights for approximately one month between the conclusion of Experiment 1 and the beginning of the present investigation.

Apparatus

The same experimental chambers described in Experiment 1 were used.

Procedure

The general details of the trace schedules used here were identical to those described in the acquisition phase of Experiment 1. Briefly, a 12-sec presentation of an orange light on the center key served as the CS. A trace inter-

val, during which stimulus conditions were identical to those between trials, was timed from the offset of the orange keylight to the onset of the food hopper. A 4-sec food hopper marked the end of each trial. A variable ITI averaging 160 sec was timed from the offset of the food presentation to the onset of the next CS period. A daily session consisted of 10 trials.

Each subject was initially placed on the trace autoshaping procedure with a 12-sec trace interval between CS offset and delivery of the food US. After 12 days of this procedure (Phase 1), the duration of the trace interval was increased to 36 sec (Phase 2). Aside from the change in the trace interval, all other parameters of the schedule remained constant. The duration of the trace interval was systematically varied in this manner for each subject according to the series of 12 phases listed in Table 3. The trace intervals were 12, 36, 60, and 120 sec. Phases comprised from 12 to 36 sessions.

RESULTS

The series of conditions in Experiment 2 may be arbitrarily divided into two parts for expository purposes. In the initial sequence, Phases 1 through 7, we were primarily concerned with whether performance at intermediate trace values would recover after exposure to longer trace intervals. In this sequence, each subject was exposed to a single trace interval for just 12 days and then advanced to the next trace interval following an ascending, and then, descending series. In the second sequence, Phases 8 through 12, the subjects were re-exposed to the same set of trace intervals for a minimum of 24 days in each phase. The aim here was to provide more time for performance to stabilize within conditions, and to determine whether the level of performance maintained at intermediate trace intervals was independent of the order of training.

Figure 6 shows the percentage of CS trials with a key peck for each subject in 4-day blocks across all experimental phases. Table 3 presents the mean percentage of trials with a key peck and mean response rates for the last 4-day block in each phase. Across Phases 1 through 4, both the response rate and the percentage of CS trials with a key peck decreased as the trace interval was increased to

120 sec. However, when the trace interval was shortened across Phases 5 through 7, there was little evidence of recovery at traces exceeding 12 sec. Three of the four subjects showed substantial increases in the percentage of CS trials with a key peck at the 12-sec interval, although the original high percentage of trials with a key peck had not recovered within the 12 days of Phase 7. The fourth subject also showed some recovery of key pecking during this condition, but maintained a relatively low percentage of trials with a key peck. Observations during the trial periods revealed that this subject also showed an increase in key-directed behavior during this phase. However, key pecking was largely replaced by energetic bobbing and nodding movements of the head immediately in front of the key, only occasionally resulting in key contacts.

The effects of prior training on the level of maintained performance is most clearly seen by comparing the percentage of CS trials with a key peck under the 36-sec trace in Phases 2 and 8 (following training at a 12-sec trace interval) with performance under the same 36-sec trace schedule in Phases 6 and 10 (following training at the 60-sec and 120-sec trace intervals, respectively). When the subjects were previously responding to the CS under the 12-sec procedure, they continued to key peck on nearly half of the CS trials under the 36-sec trace; however, when little responding was directed to the CS under the longer traces, transfer to the 36-sec procedure did not increase the percentage of trials with a key peck. In Phase 10, for example, key pecks were obtained on less than 25% of the CS trials.

A similar observation can be made for the percentage of CS trials with a key peck under the 60-sec trace procedure. Compare performance under the 60-sec trace in Phase 3 (following training at 12-sec and 36-sec trace intervals) with performance under the 60-sec trace in Phase 5 (after training with a 120-sec trace interval). Again key pecking following the shorter trace procedure was maintained at a higher level than under the same procedure following training at the 120-sec trace. In addition, following the recovery of key-directed pecking in Phase 11 (a 12-sec trace procedure), two of the four subjects showed extended maintenance of signal-directed key pecking under the 60-sec trace interval in Phase 12. (Note, one subject was dropped from the study

after 24 days in Phase 12, when it developed respiratory problems.)

DISCUSSION

As in Experiment 1, signal-directed pecking was an inverse function of the trace interval. However, the amount of behavior maintained

at intermediate trace intervals was clearly influenced by the level of performance in the preceding phase. These results make it difficult to compare the within-subject trace gradients with the between-subjects gradient obtained in Experiment 1. The within-subject gradient obtained in the increasing trace series

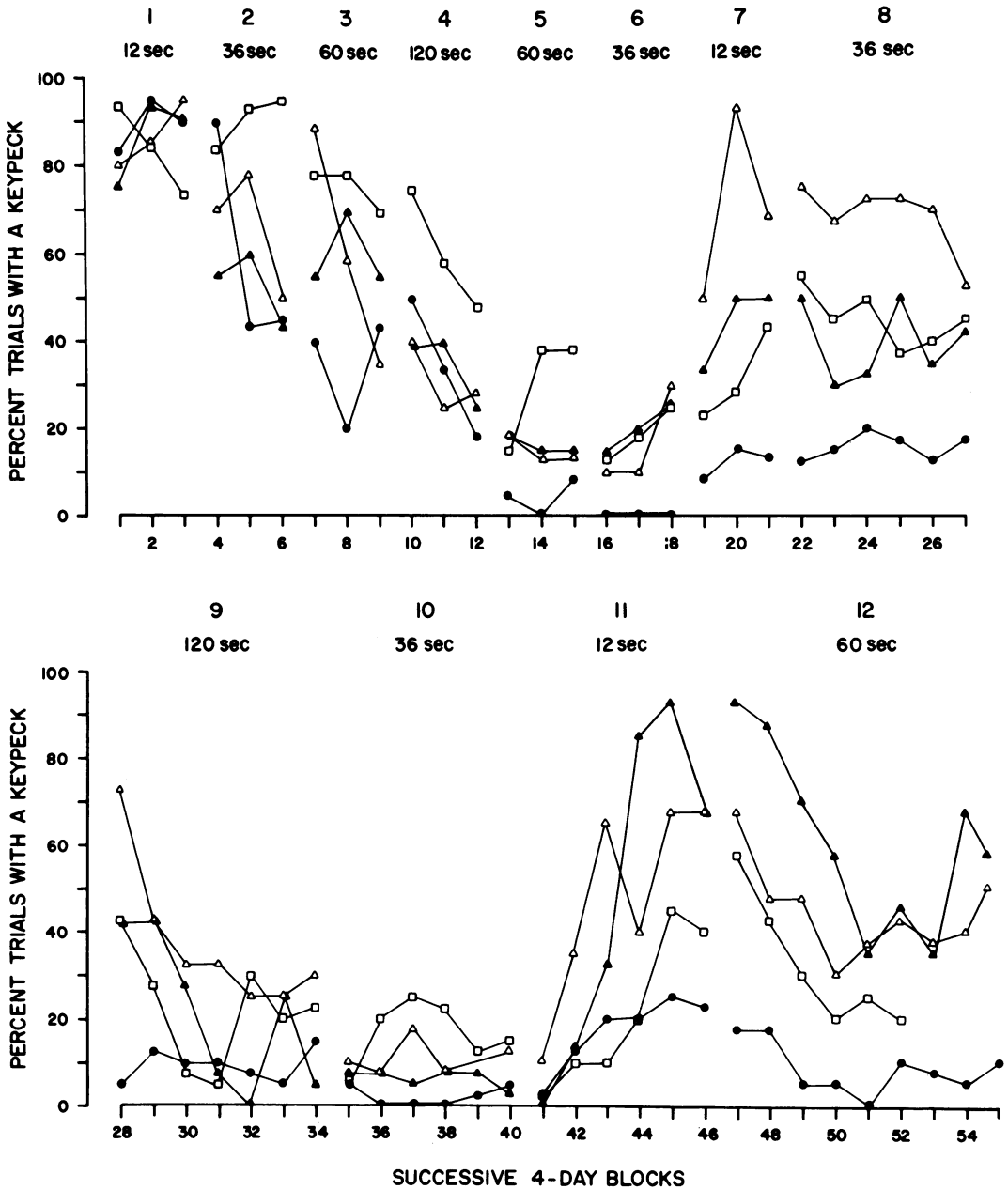


Fig. 6. The percentage of CS trials with a key peck for individual subjects across successive 4-day blocks in Experiment 2. Numbers across the top part of the figure correspond to the successive phases shown in Table 3. Symbols for individual subjects correspond to the running position in Table 3 as follows: filled circle, 1; unfilled square, 2; unfilled triangle, 3; filled triangle, 4.

was generally higher than that found in Experiment 1, but the gradient obtained in the decreasing series was generally lower than the between-subject gradient. It is noteworthy that, despite this lowered gradient, the pigeons consistently reacquired signal-directed pecking at the 12-sec trace. In fact, across the entire 220 days of Experiment 2, the subjects were never exposed to traces shorter than 12 sec.

The asymptotic level of performance produced by a conditioning procedure may be readily recoverable after interpolated treatments or, alternately, it may vary depending on the effects of the interpolated procedures. In the former condition, the behavioral system shows *true stability*; the latter condition has been termed *metastability* (see Staddon, 1965). Models for this second type of stability can be described as path dependent. Examples of path-dependent effects include the maintenance of behavior under lean reinforcement schedules (Frey & Sears, 1978), and the temporal patterning of behavior under schedules reinforcing selected interresponse times (Staddon, 1965). The current trace conditioning procedure appears to provide another example.

Staddon (1965) has noted the similarity between progressive changes in timing behavior under schedules requiring temporal discriminations, and the formation of learning or response "sets" along continua in more familiar discrimination learning tasks. In the present experiment, subjects that responded to the CS under the 12-sec trace conditioning procedure continued to respond to the CS in the 36-sec trace procedure, as they would to a more predictive CS. However, after training with the CS in a relatively unpredictable temporal relation to food (the 120-sec trace procedure), the subjects were less likely to respond to the CS as a predictive signal for food under the same 36-sec trace procedure. The suitability of these data to a learning or response set analysis is clear.

GENERAL DISCUSSION

The present results replicate and extend those of Newlin and LoLordo (1976) regarding trace autoshaping. Like Newlin and LoLordo, we found that autoshaped key pecking was inversely related to the stimulus-reinforcer interval. Further, the rate of key pecking was markedly higher during the keylight CS than during the subsequent trace interval. Finally,

although only occasionally observed by Newlin and LoLordo, we found that most key pecking to the CS occurred shortly after its onset (Wasserman, 1973); we also found a similar tendency for key pecking during the trace interval to occur shortly after CS offset.

Our most significant extension of the work of Newlin and LoLordo involved the parametric study of stimulus-reinforcer delays over a broad range of trace values. Here, as in work with delayed matching-to-sample procedures in pigeons (Grant & Roberts, 1973; Roberts & Grant, 1976), we found a decreasing function between control over behavior and the time since a prior stimulus. Additionally, the delays over which autoshaped responding was maintained (36- and even 60-sec traces) were near the maximal retention intervals obtained with pigeons in delayed-matching research (Grant, 1976; Nelson & Wasserman, 1978). As such, these findings suggest that the same memory processes are involved in trace conditioning as in the more complex discriminations of contemporary memory paradigms. Similarly, Staddon (1974; Staddon & Innis, 1969) has proposed that the temporal pattern of behavior found under free-operant fixed interval schedules is controlled by memory traces of prior reinforcers (Maki, Moe, & Bierley, 1977).

Aside from its accord with research in animal memory, the present interstimulus interval findings are generally consistent with the model of temporal control proposed by Staddon and Simmelhag (1971). If one assumes that pecking is a prominent terminal response under periodic food schedules, then at longer trace intervals the CS might simply provide a temporal marker and rather passively sample the pigeon's behavior at times less likely to involve terminal responses like pecking. At especially long trace values, the CS might even promote competing interim behavior. Unfortunately, more detailed consideration of our results poses problems for this account. Most problematical is the fact that responding during both the CS and the trace interval generally fell, rather than rose as the reinforcer drew nearer in time. Either one must assume that key pecking is not a terminal response, or posit that a rather more active role is played by the CS and other environmental stimuli in controlling the form, frequency, and direction of terminal behaviors (see Staddon & Simmelhag, 1971, p. 34). The former is a

somewhat awkward proposition as it would appear to predict a nonmonotonic rather than a monotonic decreasing interstimulus function; the latter would appear to be a more viable interpretation as it receives support from a variety of other autoshaping and conditioning sources (Wasserman, 1981).

Regardless of the specific theoretical context, our data join a now substantial body of evidence which shows close harmony between the conditioning of the pigeon's key peck with stimulus-reinforcer procedures and other responses learned with Pavlovian procedures.

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